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DETERMINATION OF WIDTH AND LUMINANCE OF A CATHODE-RAY-TUBE TRACE

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FOREWORD

This report was prepared by Columbia University under USAF Contract No. AF 33(038)-22616 covering work on Visual Factors in Cathode Ray Tube Data Presentation. The contract was initiated under a project identified by Research and Development Order No. 694-45, Presentation of Data on Radar Scopes, and was administered by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, with Dr. Kenneth T. Brown acting as Project Engineer.

ABSTRACT

A method is described for specifying cathode ray tube (CRT) traces in terms of visual measures of width and central luminance. Trace width is measured with an image doubler which produces two parallel images of the CRT trace; width is defined in terms of the distance between the centers of the two images when they just appear to merge. Central luminance of the trace is measured with a magnifying system in conjunction with the Macbeth illuminometer. The magnifier produces a real image of the trace sufficiently enlarged to fill the field of the Macbeth. Matching is performed in the usual way, and the appropriate conversion factor applied to the Macbeth reading. Estimates of intra-observer and inter-observer variability are given for width and luminance measures. The method of measuring central luminance is compared experimentally with an alternative method involving a direct monocular match.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

Robert H Blount

ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

INTRODUCTION

Research on factors affecting the visibility of cathode ray tube (CRT) displays encounters the problem of specifying the visual stimulus properties of such displays. This problem is complicated by two facts: the areas of high luminance (target pips or the trace itself) are small, and the boundaries between light and dark areas are not sharp. For example, one of the simplest types of display consists of a bright, straight-line trace against a dark background (as in the A-scan type of radar presentation). The width of the trace is only of the order of one millimeter, and the edges of the trace are not sharply defined, shading gradually into the background. Because of this, different methods of measurement yield different values for the trace width. In addition, the value obtained for trace luminance will vary, depending on whether the method used actually measures luminance at the center of the trace (central luminance) or average luminance over the width of the trace.

A complete specification of such a stimulus would give the distribution of luminance across the width of the trace. To obtain this distribution would be laborious, and would require an instrument capable of measuring the luminance of an area 0.1 mm. or less in diameter. (The photoelectric photometer described by Hamburger and King (1948) used an area about 0.5 mm. in diameter but could presumably be adapted for smaller areas.) The present note describes an alternative procedure, in which the CRT trace is specified in terms of a measure of central luminance obtained by visual match, together with a measure of trace width.

TRACE WIDTH

Since the CRT trace does not in fact have any definite edges, any measure of trace width must rest upon a convention of some sort. The convention here adopted is as follows. Two identical, parallel traces are brought closer and closer together until they just appear to merge (that is, until an observer can no longer distinguish them as two separate traces). The distance between the centers of the two traces when merging occurs is defined as the width of either trace. This is similar to the so-called raster method of measuring spot or trace width which is used in connection with cathode ray tubes designed for television and other applications.

This method may be applied to the single trace by the use of a trace doubler, an optical system which produces two parallel, side-by-side images of the trace, whose separation is known and can be varied. To measure the width of a given trace, it is viewed through the doubler and the separation of the two images varied until they just merge. The separation of the two images is then the width of the trace according to the above definition.

The essential parts of the image doubler are indicated in Fig. 1. The trace whose width is to be determined appears on the face of the CRT.

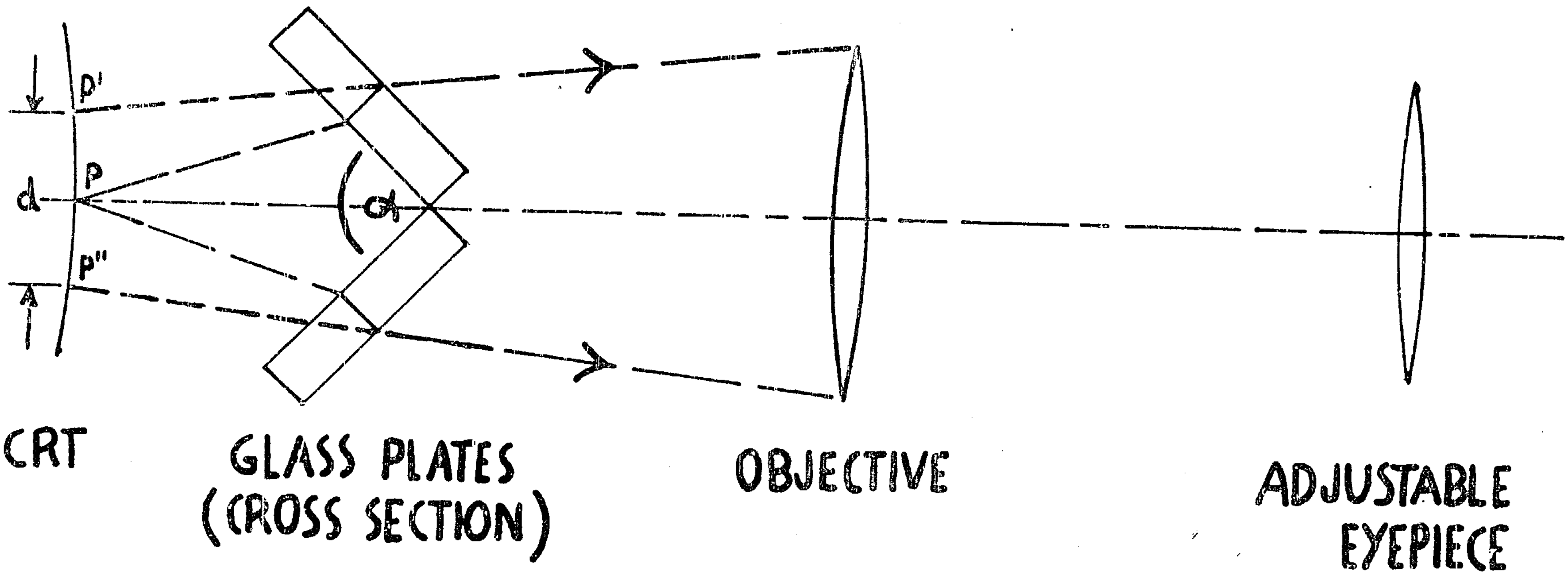

FIG.1. SCHEMATIC DIAGRAM OF IMAGE DOUBLER

Two glass plates, approximately 2 mm. thick, are mounted so that they make contact along one edge, and so that the angle α between them may be varied. The line of contact between the plates intersects the optical axis, is perpendicular to it, and is parallel to the CRT trace. Light from the trace passing through one of the plates emerges unchanged in direction but shifted away from the inner edge, due to refraction as the light enters the glass. The light passing through the other plate is displaced in the opposite direction. Thus a bundle of light rays coming from any point P on the trace will be split by the plates into two bundles, which behave as if they came from two points, P' and P", lying in the same transverse plane as the actual trace, but separated by a distance d. The size of d depends on the thickness of the plates, their index of refraction, and the angle α between them. The two bundles from each point on the trace fall on opposite sides of the objective, which forms two real images of the trace. These images are similar to those that would be obtained if two parallel traces with their centers separated by a distance d, were being viewed directly by the objective without the intervention of the plates. Accordingly, when the two images, viewed through the eyepiece, just merge, the displacement d between the apparent sources of the two images is equal to the width of each of the apparent sources, and therefore equal to the width of the actual trace. This displacement d can be determined by putting a finely ruled scale in place of the CRT. Viewed through the doubler, two scales are seen, displaced with respect to each other. The amount of this apparent displacement is the trace width d.

The procedure for measuring the width of a given trace thus involves two steps: 1) adjusting the angle α until the two images of the trace seen through the doubler just merge; 2) determining the value of d for this α.

When it is desired to obtain a trace of a given width, the above procedure may be reversed. The angle α is set so that the displacement between the two images of the scale is equal to the desired trace width. Then the CRT trace is viewed through the doubler, and the Focus control of the CRT display adjusted until the two images of the trace just merge.

Intra-observer and inter-observer variability with this method have been estimated from measurements made on a type 5CP4A CRT. The procedure for obtaining a trace of a given width was used to obtain trace widths of 0.75, 1.0, and 1.5 mm. at a number of different values of central trace luminance (see below). These values were as follows: for the 0.75 mm. width, eight luminance values ranging from 0.128 to 154 millilamberts; for the 1.0 mm. width, nine values from 0.216 to 171 millilamberts; for the 1.5 mm. width, eleven values from 0.087 to 184 millilamberts. For each trace width, five or more determinations were made at each luminance value, yielding five or more values of the Focus control setting. From all the settings for a given trace width, the probable error of the determinations made by a single observer at that width was determined. This was converted into trace width units, and expressed as a percentage of the trace width concerned. This percent probable error is the percent deviation from the mean of a series of observations which is exceeded by just one-half of the observations.

The intra-observer variability of one observer, with considerable practice in making trace width determinations, is given as the estimated percent probable error for each trace width. The number of determinations on which each figure is based is given in parentheses: 0.75 mm. 4 percent (60 readings); 1.0 mm., 3.5 percent (65 readings); 1.5 mm., 2.5 percent (105 readings).

The results of smaller series of observations (of the order of 15 readings) made by two other, unpracticed observers yield higher probable errors, up to twice those given above. It is believed that these differences in intra-observer variability are principally a function of practice in making the determinations. Intra-observer variability shows no consistent relation to trace luminance, except that there is some tendency for variability to be greater at the very lowest luminance values than at higher levels.

Inter-observer variability has been estimated by comparing the data of three observers, each making five determinations for a trace width of 0.75 mm., at luminance values of 3.97, 78.1, and 154 millilamberts. Each set of five determinations was averaged, and the range of the average values for the three observers was computed for each luminance value. The average range of the values obtained by three different observers was 18 percent of the trace width. Although calculation of the average deviation of a sample of three gives a very crude estimate of the population variability, it may be helpful in comparing inter-observer with intra-observer variability. As estimated from the average deviation of the values of the three observers from their mean, the percent probable error of the determinations of a single observer is 7 percent.

The question arises as to what extent measurements made on a CRT will be affected by variations in the CRT and its circuits over a period of time. A comparison of two sets of trace width determinations taken six weeks apart indicates that the effect of this source of variability on trace width is not great enough to be detectable with the method here described.

CENTRAL LUMINANCE

A CRT trace of the order of one millimeter in width is not wide enough to fill the field of the Macbeth illuminometer. Luminance can nevertheless be measured by visual, as opposed to photoelectric means, through the use of an optical system which provides an image of the trace sufficiently magnified to fill the Macbeth field.

The optical system of the magnifier is diagrammed in Figure 2. Two lenses mounted in contact, with a total power of 42 diopters, can be moved inside a tubular housing so that the left-hand lens surface is anywhere between 2 and 3 cm. from the open end of the tube. This end of the tube, protected by a felt ring, rests against the face of the CRT. The other end of the tube holds a collar into which the cylindrical projection of the Macbeth head fits snugly. The lenses form a real image of the CRT trace just to the left of the opening B in the Lummer-Brodhun

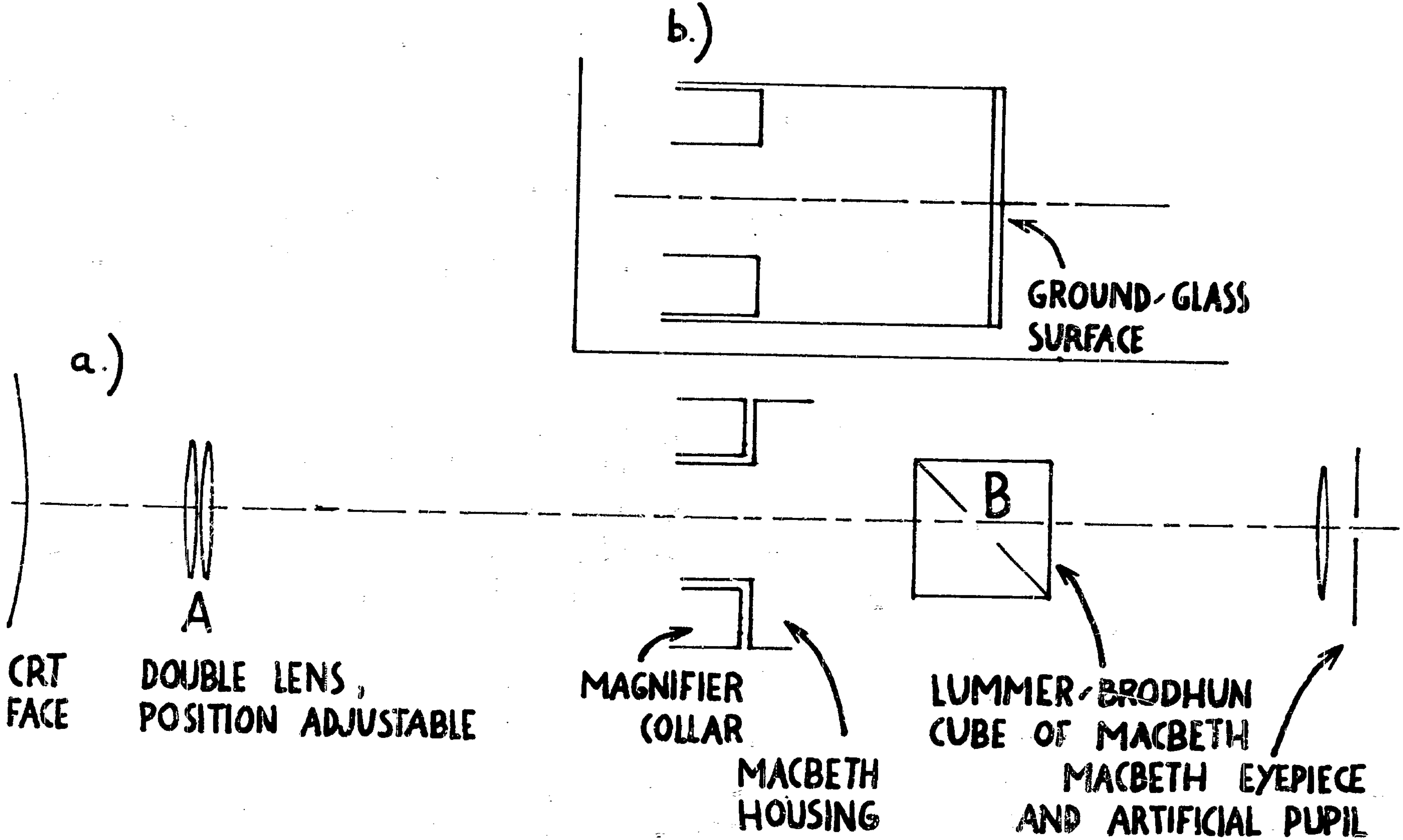

FIG.2. MAGNIFIER AND MACBETH CUBE

cube of the Macbeth, 28.6 cm. from the CRT face. The image is magnified approximately 7 diameters and is therefore larger than the opening, which is about 3 mm. in diameter. The light from this image therefore fills the central field of the Macbeth and can be matched to the standard field.

The luminance of the magnified trace image will obviously be different from that of the trace itself, and it is therefore necessary to calibrate the magnifier-Macbeth combination. In order for this calibration, described below, to be meaningful, it is essential that the real image of the trace fall always at the same point, just to the left of the opening B. This is ensured by the use of a cap containing a ground-glass screen, which can be fitted over the magnifier collar in place of the Macbeth. When this cap is in place, the ground-glass surface is exactly at the position where the image is to be formed. By adjusting the position of the lenses A, the trace image can be brought into focus at this point.

The procedure for making a luminance reading with the magnifier-Macbeth combination includes the following steps: 1) With the ground-glass screen in place and the open end of the magnifier against the CRT face, the image is brought into focus on the screen. 2) With the Macbeth seated firmly in the collar of the magnifier and the open end of the magnifier against the CRT face, the position of the magnifier or the trace is adjusted transversely until the trace appears in the field of the Macbeth. 3) The standard field of the Macbeth is matched to the brightest part of the central field, and the Macbeth reading recorded. The brightest part of the field is taken in order to get the best possible estimate of the luminance at the center of the trace.

The magnifier was calibrated with the aid of a simulated trace made by placing an opaque mask, out of which was cut a slit one millimeter wide, over an extended light source whose luminance could be measured directly with the Macbeth. This gave a light source similar in shape to the CRT trace, and of known luminance. The simulated trace was viewed through the magnifier-Macbeth combination according to the above procedure and a Macbeth reading obtained. This figure, divided into the actual luminance of the simulated trace, is the calibration constant of the magnifier. Readings obtained with the magnifier must be multiplied by this constant to obtain the central luminance value of the trace being measured.

An estimate of the accuracy of the calibration constant obtained by this method can be made from the results of calibrations conducted on six different days. Each of these calibrations was based on four or more readings with the magnifier. The average value of the calibration constant is 1.51. The estimated probable error of this value is 2.5 percent.

Intra-observer variability of luminance measurements made with the magnifier-Macbeth arrangement may be estimated from data obtained by one observer, consisting of five determinations at each of eight or more luminance levels for each of three trace widths. (The trace widths and luminance levels are those referred to earlier in connection with the estimation of intra-observer variability of trace width measurements.) The average deviation of each set of five readings was expressed as a percent of the average reading. The average percent deviation of all readings was

then computed, and from it the percent probable error of a single luminance reading is estimated at 3 percent. The percent probable error of the average of five readings made at a given setting would thus be 1.3 percent.

The inter-observer variability was estimated from the data of three observers, each making five or more luminance readings at each of the following combinations of trace width and luminance level: 1 mm., 3.82 millilamberts; 1 mm., 86.8 millilamberts; 1 mm., 171 millilamberts; 0.75 mm., 102 millilamberts; 1.5 mm., 57 millilamberts. The readings of each observer were averaged for each of the five conditions, and the range of the average values for the three observers was computed for each condition. The average range of the values obtained by three different observers was 7.4 percent of their mean luminance value. Again, estimating the probable error from the average deviation of three observers, the estimated percent probable error of the measurements of a single observer is 2.5 percent.

The effect of variations within the CRT and its circuits is greater in the case of trace luminance than of trace width. In order to minimize variations due to fluctuations in line voltage, the input to the Dumont 304H oscilloscope used was monitored at 117.5 volts. The effect of CRT and circuit variations was assessed by making repeated luminance measurements at the same control settings, eight times over a period of three weeks. As estimated from these data, the percent probable error of readings made on any one occasion, due to CRT and circuit variations, is 2.3 percent.

It is important to have an estimate of variations of this sort on applications where trace width and luminance for various settings of the Intensity and Focus controls are measured once and the resulting calibration of the CRT display used over a period of time. Variations over extended periods may be greater than those indicated above. It is advisable to check the initial calibration occasionally by repeating the luminance measurement at a single "reference" set of control settings, in the middle of the width and luminance range used. Even if the deviation from the initial calibration is substantial, it may not be necessary to repeat the entire calibration. If the Intensity and Focus controls are left at the "reference" settings and some other control (e.g., Sweep Frequency or, if the trace is horizontal, Horizontal Gain) used to bring trace luminance back to its value in the initial calibration, the effect will be to reinstate the entire calibration. The trace width calibration is unaffected by this operation within rather wide limits.

The present method of measuring central luminance of a CRT trace has been used to calibrate the 5CP4A CRT previously mentioned. The range of central luminance obtained is from about 0.1 to about 180 millilamberts. This maximum luminance value is considerably less than the value of 1000 millilamberts reported for PPI displays by Williams and Bartlett (1948). This may be due to the fact that their measurements were made on a P7 long-persistence phosphor. The radiation built up in the second, phosphorescent layer of such a phosphor may be considerably greater than that from a relatively short-persistence phosphor such as the P4 used in the

5GP4A CRT. The possibility that the difference in maximum luminance is due to differences in CRT or circuit construction or in methods of measurement should also be explored.

The lower limit of approximately 0.1 millilamberts, in the calibration referred to above, is set primarily by the coarseness of the Intensity control on the CRT, which does not permit repeatable settings for lower luminance levels. With a control arrangement which does permit such settings, lower luminance values could be measured, although as noted in the "Discussion", intra-observer variability would be greater. The upper and lower limits of luminance measurement possible with the magnifier-Macbeth combination are those of the Macbeth alone, multiplied by 1.5, the calibration factor of the magnifier.

COMPARISON WITH DIRECT MONOCULAR MATCHING METHOD

The measurement of trace width and central luminance is only one of several possible methods of specifying, by visual means, the stimulus properties of a CRT trace. An alternative approach consists in matching the CRT trace directly with a comparison stimulus of similar shape, i.e., a narrow strip of light of the sort previously described as a simulated trace. The match may be monocular or binocular. It is of considerable interest to know the relationship between measurements obtained by these different methods. A comparison of the central luminance and direct monocular matching methods is described below.

Light from a simulated trace of known luminance, similar to that previously described, was reflected into the eye from a front-silvered mirror in such a manner that it appeared side by side with the real CRT trace, which was viewed directly. The real and simulated traces were at the same optical distance from the eye, and were approximately matched for color by the use of an appropriate filter between the simulated trace and the mirror. The simulated trace was one millimeter wide, and it was matched to a CRT trace of the same width, as measured by the doubler method. The apparent distance between the parallel traces during matching was about equal to the trace width. The match was made by varying the density of a polaroid, placed between the simulated trace and the mirror, until the two traces appeared equally bright. Matches were made in the range of central luminance 80 to 110 millilamberts. The results are expressed as the ratio between the central luminance as measured with the magnifier and the "average" luminance as measured by direct monocular match.

Comparisons made on four different occasions, each involving several luminance determinations, give an average value of the magnifier-monocular ratio of 0.82. The estimated probable error of this figure is 7 percent.

This result indicates that central luminance as measured with the magnifier is <u>less</u> than "average" luminance as measured by direct monocular match. If the luminous area of the CRT were really no wider than the trace width as determined by the doubler, the central luminance should be <u>greater</u> than the average luminance. Actually, some light reaches the eye from a wider area, since the trace shades off gradually into the background.

Presumably, the contribution which this light makes to the total visual effect in the direct monocular match (but not in measurements made with the magnifier) explains why the magnifier-monocular ratio is less than one.

DISCUSSION

The chief advantages and limitations of the present method of measuring trace luminance are those of any visual method of stimulus specification. Since the color temperature of the CRT trace will usually be different from that of the standard field of the Macbeth, inter-observer differences in photopic or scotopic luminosity curves may cause observers to disagree. Overall inter-observer variability, however, will presumably be about the same at photopic and scotopic levels. At luminance levels below the photopic range, intra-observer variability increases. In most work with CRT displays very low luminance levels will probably not be used, so that intra-observer variability may not be a great problem. In such work, the use of a visual measure avoids the problem, encountered in photoelectric methods, of matching the sensitivity curve of the human eye.

The doubler method of measuring trace width depends on the discrimination of the difference in luminance between the center of either trace image and the point midway between the two centers. If the discriminatory threshold $\Delta I/I$ were constant for all luminance levels, the doubler method would be equivalent to defining trace width as the distance between those points on either side of the trace center at which luminance falls off to some specified, fixed fraction of its value at the trace center. In reality, threshold $\Delta I/I$ is smaller at high than at low luminance levels. Consequently, the ratio between the trace width measured with the doubler and the trace width that would be obtained by measuring between points representing a fixed fraction of central luminance, will be smaller at high than at low luminances. The importance of this factor might be assayed through its effect on the magnifier-monocular ratio (above), since it would tend to make this ratio decrease as luminance increases.

Some modifications that would increase the usefulness of the magnifier method may be suggested. The area of the trace from which light reaches the central field of the Macbeth could be reduced considerably, partly by increasing the magnification of the trace image, but more especially by the use of a Lummer-Brodhun cube with a smaller central aperture. The central field of the Macbeth could probably be reduced in this way to one-half its usual diameter without affecting the ease of making a match.

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